Atomicity via Source-to-Source Translation

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Atomic

An *easier-to-use* and *harder-to-implement* primitive

```
void deposit(int x){
synchronized(this){
  int tmp = balance;
  tmp += x;
  balance = tmp;
}}
```

```
void deposit(int x){
atomic {
  int tmp = balance;
  tmp += x;
  balance = tmp;
}}
```

lock acquire/release

(behave as if)
no interleaved computation

Why the excitement?

- Software engineering
  - No brittle object-to-lock mapping
  - Composability without deadlock
  - Simply easier to use

- Performance
  - Parallelism unless there are dynamic memory conflicts

But how to implement it efficiently…

This Work

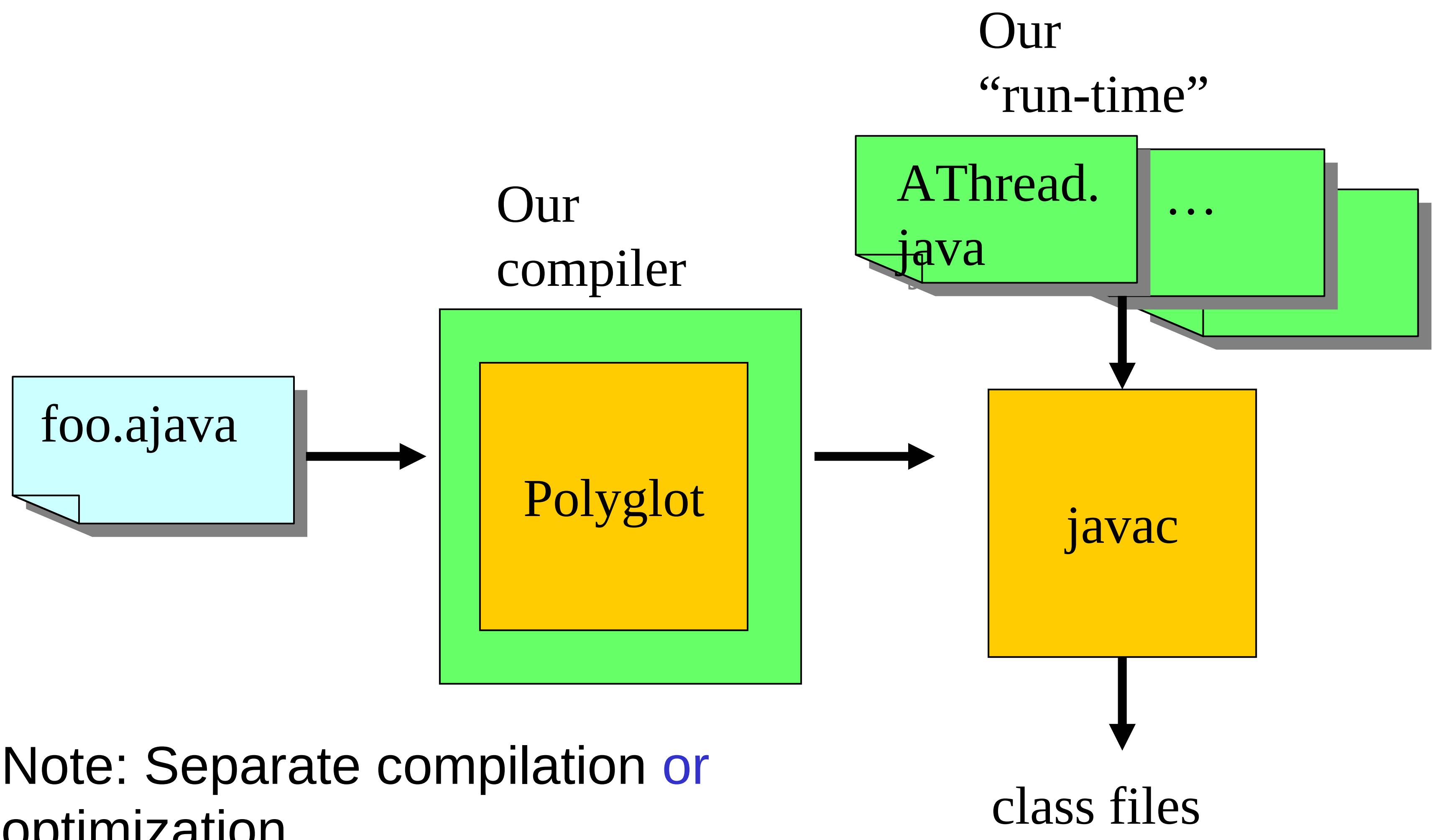
Unique approach to "Java + atomic"

1. Source-to-source compiler (then use any JVM)
2. Ownership-based (no STM/HTM)
   – Update-in-place, rollback-on-abort
   – Threads retain ownership until contention
3. Support "strong" atomicity
   – Detect conflicts with non-transactional code
   – Static optimization helps reduce cost

Outline

- Basic approach
- Strong vs. weak atomicity
- Benchmark evaluation
- Lessons learned
- Conclusion

System Architecture



Note: Separate compilation or optimization

Key pieces

- A field read/write first *acquires ownership* of object
  - In transaction, a write also *logs the old value*
  - No synchronization if already own object
- Some Java cleverness for efficient logging
- *Polling* for releasing ownership
  - Transactions rollback before releasing
- Lots of omitted details for other Java features

Acquiring ownership

All objects have an **`owner`** field

```
class AObject extends Object {
  Thread owner; //who owns the object
  void acq(){…} //owner=caller (blocking)
}
```

Field accesses become method calls

- Read/write barriers that acquire ownership
- Calls simplify/centralize code (JIT will inline)

Field accessors

```
D x; // field in class C
static D get_x(C o){
  o.acq(); return o.x;
}
static D set_nonatomic_x(C o, D v) {
  o.acq(); return o.x = v;
}
static D set_atomic_x(C o, D v) {
  o.acq();
  ((AThread)currentThread()).log(…);
  return o.x = v;
}
```

Note: Two versions of each application method, so know which version of setter to call

Important fast-path

If thread already owns an object, no synchronization

```
void acq(){
 if(owner==currentThread()) return;
 …
}
```

- Does *not* require sequential consistency
- With “owner=currentThread()” in constructor, thread-local objects *never* incur synchronization

Else add object to owner’s “to release” set and wait

- Synchronization on owner field and “to release” set
- Also fanciness if owner is dead or blocked

Logging

- *Conceptually*, the log is a stack of triples
  - Object, “field”, previous value
  - On rollback, do assignments in LIFO order
- Actually use 3 coordinated arrays
- For “field” we use singleton-object Java trickery:

```
D x; // field in class C
static Undoer undo_x = new Undoer() {
  void undo(Object o, Object v) {
    ((C)o).x = (D)v;
  }
}
…currentThread().log(o, undo_x, o.x);…
```

Releasing ownership

- Must "periodically" check "to release" set
  - If in transaction, first rollback
    - Retry later (after backoff to avoid livelock)
  - Set owners to **`null`**
- Source-level "periodically"
  - Insert call to **`check()`** on loops and non-leaf calls
  - Trade-off synchronization and responsiveness:

```
int count = 1000; //thread-local
void check(){
 if(--count >= 0) return;
 count=1000; really_check();
}
```

But what about…?

Modern, safe languages are big

See paper & tech. report for:

constructors, primitive types, static fields,
class initializers, arrays, native calls,
exceptions, condition variables, library classes,
…

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Strong vs. weak

- Strong: atomic not interleaved with any other code
- Weak: semantics less clear
  - “If atomic races with non-atomic code, undefined”
    - Okay for C++, non-starter for safe languages
  - Atomic and non-atomic code can be interleaved
    - For us, remove read/write barriers outside transactions

- One common view: strong what you want, but too expensive in software
  - Present work offers (only) a glimmer of hope

Examples

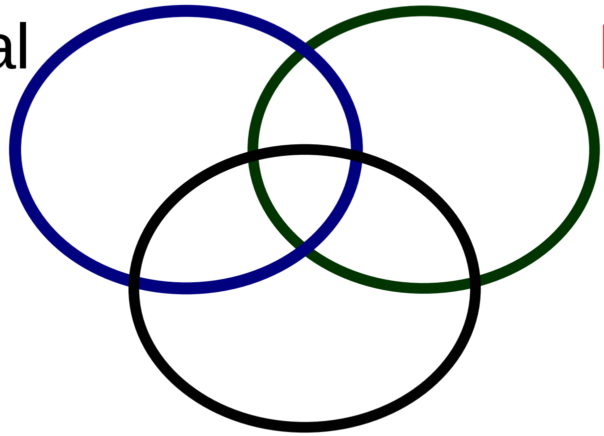
```
atomic {                          ||   x=null;
  if(x!=null)                     ||
    x.f=42;                       ||
}                                 ||
```

```
atomic {                          ||   print(x);
  x=secret_password;              ||
  //compute with x                ||
  x=null;                         ||
}                                 ||
```

Optimization

Static analysis can remove barriers outside transactions

- In the limit, “strong for the price of weak”



- This work: Type-based alias information
- Ongoing work: Using real points-to information

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Methodology

- Changed small programs to use atomic (manually checking it made sense)
  - 3 modes: “weak”, “strong-opt”, “strong-noopt”
  - And original code compiled by javac: “lock”
- All programs take variable number of threads
  - Today: 8 threads on an 8-way Xeon with the Hotswap JVM, lots of memory, etc.
  - More results and microbenchmarks in the paper
- Report slowdown relative to lock-version and speedup relative to 1 thread for same-mode

A microbenchmark

crypt:

- Embarrassingly parallel array processing
- No synchronization (just a main Thread.join)

	lock	weak	strong-opt	strong-noopt
slowdown vs. lock	--	1.1x	1.1x	15.0x
speedup vs. 1 thread	5x	5x	5x	0.7x

- Overhead 10% without read/write barriers
  - No synchronization (just a main Thread.join)
- Strong-noopt a false-sharing problem on the array
  - Word-based ownership often important

TSP

A small clever search procedure with irregular contention and benign purposeful data races

– Optimizing strong cannot get to weak

	lock	weak	strong-opt	strong-noopt
slowdown vs. lock	--	2x	11x	21x
speedup vs. 1 thread	4.5x	2.8x	1.4x	1.4x

Plusses:

- Simple optimization gives 2x straight-line improvement
- Weak “not bad” considering source-to-source

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Some lessons

1. Need multiple-readers (cf. reader-writer locks) and flexible ownership granularity (e.g., array words)
2. High-level approach great for prototyping, debugging
   – But some pain appeasing Java's type-system
3. Focus on synchronization/contention (see (2))
   – Straight-line performance often good enough
4. Strong-atomicity optimizations doable but need more
5. Modern language features a fact of life

Related work

Prior software implementations one of:

- Optimistic reads and writes + weak-atomicity
- Optimistic reads, own for writes + weak-atomicity
- For uniprocessors (no barriers)

All use low-level libraries and/or code-generators

Hardware:

- Strong atomicity via cache-coherence technology
- We need a software and language-design story too

Conclusion

Atomicity for Java via source-to-source translation and object-ownership

- Synchronization only when there's contention

Techniques that apply to other approaches, e.g.:

- Retain ownership until contention
- Optimize strong-atomicity barriers

The design space is large and worth exploring

- Source-to-source not a bad way to explore

To learn more

- Washington Advanced Systems for Programming

  wasp.cs.washington.edu

- First-author: Benjamin Hindman
  - B.S. in December 2006
  - Graduate-school bound
  - This is just 1 of his research projects

[Presentation ends here]

Not-used-in-atomic

This work: Type-based analysis for not-used-in-atomic

- If field `f` never accessed in atomic, remove all barriers on `f` outside atomic
- (Also remove write-barriers if only read-in-atomic)
- Whole-program, linear-time

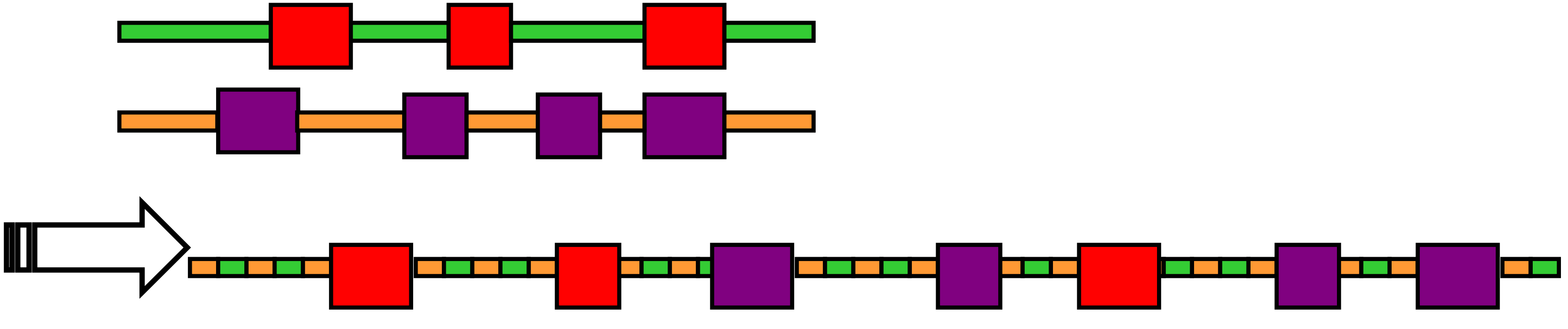
Ongoing work:

- Use real points-to information
  - Present work undersells the optimization's worth
- Compare value to thread-local

Strong atomicity

(behave as if) no interleaved computation

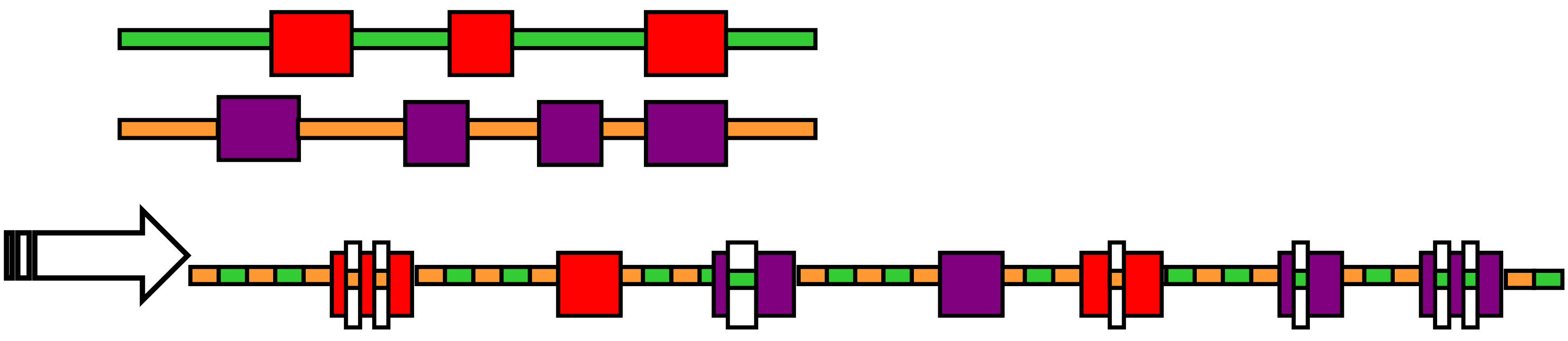
- Before a transaction “commits”
  - Other threads don’t “read its writes”
  - It doesn’t “read other threads’ writes”
- This is just the semantics
  - Can interleave more unobservably



Weak atomicity

(behave as if) no interleaved transactions

- Before a transaction "commits"
  - Other threads' transactions don't "read its writes"
  - It doesn't "read other threads' transactions' writes"
- This is just the semantics
  - Can interleave more unobservably



Evaluation

Strong atomicity for Caml at little cost

- Already assumes a uniprocessor
- See the paper for "in the noise" performance

- Mutable data overhead

	not in atomic	in atomic
read	none	none
write	none	log (2 more writes)

- Choice: larger closures or slower calls in transactions
- Code bloat (worst-case 2x, easy to do better)
- Rare rollback

Strong performance problem

Recall uniprocessor overhead:

	not in atomic	in atomic
read	none	none
write	none	some

With parallelism:

	not in atomic	in atomic
read	none iff weak	some
write	none iff weak	some

Start way behind in performance, especially in imperative languages (cf. concurrent GC)

Not-used-in-atomic

Revisit overhead of not-in-atomic for strong atomicity, given information about how data is used in atomic

	not in atomic			in atomic
	no atomic access	no atomic write	atomic write	
read	none	none	some	some
write	none	some	some	some

- Yet another client of pointer-analysis
- Preliminary numbers very encouraging (with Intel)
  - Simple whole-program pointer-analysis suffices